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ERDA Research in Fracturing Technology

By

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ABSTRACT

Research in fracturing technology for the ERDA organization is structured on (1) the development of new concepts for increasing the deliverability of natural gas from resources that are classified as marginal by present day practices and (2) the testing and transfer of new technology to the private sector. The program at the Morgantown Energy Research Center is centered about their foremost expertise in delineating and utilizing natural and induced fracture systems for enhancement of resource recovery. More recently, the research program has been expanded to include studies of foam fracturing, production history from fractured wells, cost/effectiveness of stimulation treatments and fracture mechanics as support activities for field demonstration projects. The program at the Bartlesville Energy Research Center evolves about their broad experience in stimulation technology in the marginal gas resources of the western U.S. This experience includes nuclear, explosive and more recently, massive hydraulic fracturing stimulation technology.

The ERDA organization interfaces with industry in field demonstration projects of new stimulation concepts that are potentially attractive as techniques for improving the deliverability of gas from known marginal resources. The most widely tested concept to date is the development of massive hydraulic fracturing technology utilizing new fracturing fluids and large volumes of fluid and sand to create long propped fractures. A second noteworthy concept that merits consideration as a future demonstration project includes the utilization of natural and induced fracture systems in conjunction with slanthole drilling and multiple hydraulic fracturing. Together with explosive fracturing and recompletion technology, these concepts offer the best potential for increasing the natural gas supply.

Demonstrations of field worthy technology are conducted with direct service contracts or with cost sharing government-industry contracts both of which are approaches now being pursued. ERDA participation is to provide an interface for technical contributions to the efforts and for the transfer of new technology to be accomplished. Upon successful demonstration of new stimulation techniques, it is anticipated that rapid commercialization will follow.

INTRODUCTION

The Federal Power Commission Natural Gas Technology Task Force has assessed the current status of natural gas reserves at 250 trillion cubic feet and investigated the future potential

References and illustrations at end of paper.

of new or advancing technologies which might be used to economically produce a marketable supply of natural gas.[1] Their findings delineate the major gas deposits of the Rocky Mountain regions as the most likely resources which could be converted to immediate reserves (Figure 1). Assessments of the areas that may be suitable for stimulation estimate that their proved resources are about 300 TCF of gas.[2,3]

The gas resources of the Devonian Shale of the eastern U.S. must also be considered as possible immediate additions to reserves especially because of their proximity to the large eastern markets (Figure 2). Recoverable reserves of the Devonian Shale have been estimated at 285 TCF.[4]

Since 1968, however, advances have been made in technology that now permit the natural fracture system to be mapped in a region so that the location of potential fluid conduits can be determined.[5,6,7] With this new knowledge, it is conceivable that the steps to develop these potential gas reserves can now be realized by massive hydraulic fracturing and/or drilling slant wells in a direction to intersect the natural fractures that are known to exist.[8] In certain instances, explosive fracturing techniques may be desired to augment hydraulically induced fractures or to penetrate native fracture systems for gas production.

In particular, technology now exists (1) to test how various fracturing fluids, injection rates or proppant density affect the fracture length and productivity of a conventional stimulation treatment; (2) to investigate the net effect of detonating a liquid explosive in an induced hydraulic fracture; and (3) to test the productivity from applications of large volumes, high treating pressures and heavy proppant density in massive fracture treatments in both vertical and inclined holes to determine if a particular stimulation method may be adapted for the recovery of additional natural gas.

DEVELOPMENT OF CONCEPTS

The ERDA program for development of gas resources is directed toward the testing and transfer of new technology to the private sector. A major part of this program is designed to maximize the participation of private industry by awarding cost-sharing contracts to companies actively engaged in the production of natural gas. The objective of such an approach is to evaluate the technical and economic feasibility of new stimulation techniques using the expertise and facilities of industrial organizations. The competitive RFP process is used in developing many of the contracts because it provides an equal opportunity for all interested organizations to recommend programs which address a specific objective.

The development of new concepts which hopefully will eventually be tested through contract research is actively pursued in research projects at the Morgantown Energy Research Center. The program at Morgantown is centered about their foremost expertise in delineating and utilizing natural and induced fracture systems for enhancement of resources recovery. In the evaluation of sites for development, analyses of remote sensing imagery, oriented cores and the borehole configuration of any induced hydraulic fractures are made to intelligently locate wells for optimum development of energy resources. Using this approach, fracture orientation has been defined for about 20 different production fields as fundamental information for field development. The program at Bartlesville evolves about their varied experiences in assessing stimulation technology for gas production from Project Gasbuggy up to and including a new series of MHF projects in western U.S.

Projects are now in progress to determine if improved methods of formation stimulation might be technically sound and economically attractive for production of gas from marginal resources.

These projects and their objectives are tabulated as follows:

Hydraulic Fracturing
a. New fracturing fluids--foam, liquid CO_2 and alcohol
b. Large volumes of frac fluid

Deviated Wells
a. Exposure of additional surface area per well
b. Intersection of natural fractures
c. Multiple stimulation

Fracturing Methods
a. Dynafrac--multiple vertical fractures in a stripper wells
b. Explosive Fracturing--thin layer explosives in hydraulic fractures
c. Mechanism of fracture propagation
d. Methods for control of induced fracture orientation

Evaluation of Fracture Effectiveness
a. Simulation of induced frac length from production tests
b. Measurement of induced fracture geometry

These concepts plus productivity augmentation by explosive fracturing are now being tested under various contracts in several producing regions that can be characterized as marginal. Target areas for the tests and participants in these efforts are discussed in the following section.

RESOURCES SUSCEPTIBLE TO DEVELOPMENT

The major basins of the Rocky Mountain and Appalachian states contain a very large volume of low permeability gas-bearing formations. Five areas shown in Figure 1 and Figure 2 are of sufficient thickness to warrant consideration by stimulation whereas now most of this gas cannot be produced economically with present drilling and completion techniques. This, however, does not preclude consideration of formations of lesser extent which may be resources for development on a regional or local basis.

In many areas of the basins, these gas resources are contained within very thick formations, up to 4,000 feet of gross interval with several hundred feet of net pay. The pay zones average 9 to 10 per cent in porosity and 50 to 55 per cent in water saturation. Effective permeability is quite low, ranging from 0.007 to 0.025 millidarcy. The gas content in the essentially proved area alone is about 300 trillion cubic feet in the west and an equal amount in the east (Table 1).

These gas-bearing formations are upper cretaceous and lower tertiary fluvial sandstones. The very low permeability of the sands are due to a combination of geological factors affecting deposition and cementation of the sandstones. Most of the sandstone bodies of the formation are lenticular channel fill and point bar deposits, affecting lateral and vertical continuity of the sand.

Core analysis and production histories of wells completed into the gas-bearing formations indicate that most of the economic production is attributed to the borehole intersecting natural fractures in the rock.

A directionally controlled borehole drilled at an angle of 45 to 60 degrees through these thick gas-bearing formations should intersect more natural fractures and perhaps a greater number of sandstone lenses than a vertically drilled borehole. Hydraulic fracturing and/or explosive fracturing along this inclined borehole would augment the fracture systems to increase gas production.

On the other hand, greater lateral extent might be just as effective in increasing productivity from massive hydraulic fractures in a vertical well. Considering that commercial stimulation techniques have yet to be established, it is reasonable to recommend the evaluation of one or more in given geologic basins.

GOVERNMENT--INDUSTRY RESEARCH ACTIVITIES

The possibility of using deviated wells to intersect natural fractures and to encounter more productive formation for hydraulic fracturing stimulation was proposed in a paper presented by Pasini and Overbey.[8] The possibility of using large fracture treatments to increase production from tight formations was presented in an SPE paper by Holditch and Morse.[9] Undoubtedly others may have considered these techniques prior to the dates documented above, but the movement to prove these concepts has been understandably slow because of the costs involved. More recently, Schrider, Locke, and Haynes[10] have reported on studies on the effectiveness of different hydraulic fracture treatments in low permeability reservoirs which indicate that concepted studies of fracture treatment data can yield optimum fracture design data for maximizing production.

With this background information in mind, an intermediate range research program was planned which would develop stimulation techniques for the production of natural gas. The following is a general description of the project plan.

Massive Hydraulic Fracturing Technology

Massive hydraulic fracturing technology centers about the utilization of large volumes of fluids for creating surface area connected to a wellbore and subsequent increased deliverability of natural gas. In the development thereof, geological characterization of those reservoirs which are marginally productive because of low production rates, but which contain large amounts of gas in place are in order. This includes

1. Determination of basic reservoir properties, rock type and structural setting.
2. Selection of test areas in gas fields which would provide the most information which might be used as an analog for other areas.
3. Characterization of the natural fracture system, the existing stress field and directional reservoir rock properties for each test site.
4. Optimization of the vertical height, and lateral extent of fractures induced with various fluids, rates, volumes, proppants, and number of stages needed to maximize production for a particular rock-stratigraphic-structural analog.
5. Evaluation of induced geometry via surface monitoring systems and production and pressure analyses.

Explosive Fracturing Technology

Explosive fracturing technology centers about processes advocated by two companies who currently have field demonstration capabilities

and two companies who have proposed laboratory research on new concepts for well stimulation. The only active ERDA contract is concerned with the development and evaluation of the method of well stimulation which generates multiple well bore fractures in gas or oil bearing reservoirs.

Recently, arrangements have been made for evaluating the technical and economic aspects of liquid chemical explosives in seven wells at three test sites in two different producing horizons. In this effort, sites will be selected to improve the probability of intersecting the native fracture systems with the stimulation technique.

No in-house research projects exist nor are being planned in this area of technology. Therefore, the support work and the development of new concepts for testing are solely the function of industrial concerns.

Deviated Well Technology

One aspect of deviated well technology is the utilization of a directionally-controlled, deviated wellbore to intersect natural fractures which exist in the target formation. This technique should affectively stimulate production of oil and natural gas from low-permeability, naturally fractured reservoirs.

Conceptually, the wellbore is drilled in a predetermined direction - orthogonal to the preferred orientation of the natural fracture system - and deviated from vertical at some optimum (cost vs. formation contacted) angle. If the preferred orientation of the natural fracture system can be accurately predicted, this configuration would possess a high probability of success.

Accurate prediction of the existence of natural fracture systems and the orientation of fractures comprising these systems is possible only through a thorough understanding of the forces associated with fracture creation. In this light, a major effort was conducted at Morgantown to study these forces and to assemble a comprehensive data bank which would be used to quantify these forces. The studies which comprised this effort were:

(1) Lineament analysis of remotely sensed imagery
(2) Field mapping of surface joint systems
(3) Near-surface measurement of the Earth's stress field
(4) Analysis of oriented core material

These studies were conducted in two locations: 1) Cottageville, Jackson County, West Virginia; and 2) Hazard, Perry County, Kentucky.

Results of these studies will be used to design deviated wells which are planned for these locations.

Recompletion Technology

The development of recompletion technology is needed to exploit 1) marginal gas reservoirs which were overlooked during the development of deeper formations and 2) gas wells which were stimulated with explosives. Demonstrating the mechanical and economic feasibility of completing these wells and stimulating them using newly developed techniques would open a new avenue for natural gas producers and provide a new source of natural gas.

An operating company with substantial natural gas interests has proposed a joint program with ERDA to evaluate new stimulation techniques and develop new technology for economically recovering natural gas from the Devonian Shale through recompletion and dual production of existing Clinton Sand wells.

The proposed program consists of the following work elements:

(1) Selecting the strategic areas for exploration and the specific locations of the well sites. This will be accomplished using advanced imagery mapping and conventional geology methods.
(2) Stimulating new Devonian Shale wells using experimental techniques. Drilling data, such as coring, logging, gas detector information and other formation parameters will be used to design and evaluate the stimulation treatments.
(3) Recompleting and stimulating the Devonian Shale in existing Clinton Sand wells that offset the new shale wells.
(4) Providing the results of the stimulation of the previously mentioned wells are successful, additional new wells will be stimulated.
(5) Extensive production testing and cost/effectiveness studies will be done to determine the economic success of the stimulation and recompletion techniques.

Support Technology

Although the effects of natural and induced fractures on reservoir performance has been demonstrated, few fracture systems have been well defined in these reservoirs because of the lack of adequate techniques for determining the density, direction and extent of the fractures. Considerable progress has been made on techniques for delineating reservoir fracture systems but much work remains to test, evaluate and develop these techniques for commercial application.

Active projects now being conducted by the Morgantown Energy Research Center are listed:

1. Prediction of fracture orientation from aerial photos and directional properties of oriented cores.
2. Evaluating the efficiency of foam fracturing on production.
3. Monitoring acoustic emission from propagating fractures in reservoir rocks.
4. Numerical simulation of effective fracture length from pressure buildup and production tests.
5. Statistical analysis of effectiveness of fracturing on production.
6. Mechanism of fracture propagation in stress environment.
7. Stress analysis of layered granular media during hydraulic fracturing operations.
8. Feasibility of determining fracture orientation in shallow reservoirs by changes in surface electric potential.

In addition to these activities, pioneering efforts are being tested under contract to various organizations. These projects are listed as follows:

1. Massive hydraulic fracture mapping with seismic and electric potential arrays--Sandia Corp.
2. Measure of induced fracture geometry by changes in tilt during fracturing operations--U.S.G.S.--Menlo Park, California.
3. Pulse Test Analysis of a vertically fractured well--Univ. of Tulsa.
4. Analysis of the fracturing process via numerical simulation techniques--Lawrence Livermore Lab.

All of these activities are part of or attached to the ERDA inhouse program on stimulation technology which is the mission of the Morgantown Energy Research Center. The identification of the projects established to fulfill this function and the listing of their activities are available for inspection in Table 2. Detailed descriptions of these research activities are listed in the Appendix.

Essentially, activities associated with Project No. 1 in Table 2 are directed at adequately characterizing low permeability reservoirs with regard to organic content, porosity, mineralogy, trace elements, sorption qualities and both bulk and directional mechanical properties coupled with studies of surface and subsurface geology and photointerpretation. This extensive characterization promises to be a key element in the development of a viable method of locating zones of intense fracturing.

Noteworthy concepts associated with Project No. 2 that are worthy of field testing include the utilization of natural and induced fracture systems in conjunction with slant hole drilling and multiple hydraulic fracturing as a potential method of increasing the natural gas supply. A second concept worthy of consideration is the development of large volume (MHF) fracturing techniques utilizing new fracturing fluids (liquified gas, foam). New technology in creating long propped fractures and new techniques to evaluate the net geometry created gives this project a high probability of success.

Demonstrations of field worthy technology will be conducted by either service contracts or by government-industry projects both of which are activities associated with Project No. 3. ERDA participation is to assure adherence to contracted scopes of work and to provide an interface for technical contributions to the efforts. Accordingly, the transfer of new technology will be accomplished.

PROGRAM STATUS

ERDA's role in the development of marginal gas resources by fracturing has moved from the modest single agency laboratory type research approach in FY 1974 to an interagency--industrial participation type program in FY 1975. Now, in September 1976, eleven contracts are in effect with industry for field demonstration projects of massive hydraulic fracturing technology, two contracts are in effect to assess explosive fracturing techniques as stimulation technique and four new projects are proposed. Essentially, these activities are directed at improving technology in production practices of marginal resources in the Eastern and Western Basins of the U.S. (Figure 3). An outline of the current program is summarized in Table 3.

In addition to these projects, grants (2) have been awarded to West Virginia University to investigate:

1. Mechanism of fracture propagation in reservoir rocks.
2. Prediction of in situ stress from oriented cores of the Devonian shale for field development.

These projects are coordinated with those currently in progress at the Morgantown Energy Research Center to delineate and utilize natural and induced fracture systems for enhanced recovery of natural gas.

Development work will be continued to establish methods that are generally acceptable for determining the fracture system within a

reservoir. Together with both simulated and factual recovery methods illustrating the significance of planning well patterns to utilize fracture systems, development technology is expected to be established to stimulate the marginal gas resources of the nation. Recovery of just a portion of the 250 trillion cubic feet known to exist in the west and the comparable amount identified as recoverable in the east could go a long way in reducing our annual gas deficit and provide a clean energy to meet our nation's demand for fuel.

EXPECTED RESULTS

Major benefits which should result from stimulation of low permeability reservoirs by the proposed fracturing techniques are (1) increased production rate due to more surface area exposed within the productive interval, (2) increased likelihood of intersecting natural fractures and (3) a reduction in the cost per well to produce the formation.

If successful, 1.8 to 2.5 trillion cubic feet of gas per year could be provided by 1985 from the western basins alone which would be 20 per cent of the projected unsatisfied demand in that year. Continued success in the east could match this production.

Since the component technologies are well established, it is anticipated that rapid commercialization might follow upon successful demonstration of a stimulation technique.

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APPENDIX

Remote Sensing Studies

The ERDA project on Earth Fracture Systems being conducted at the Morgantown Energy Research Center develops new and/or improved methods for detecting and delineating subsurface fracture systems and demonstrates their role in the enhanced recovery of oil and gas.

Prior work has indicated that many lineaments observed on airborne images of the earth's surface have exhibited a relationship with surface joints, fractures in cores and geologic features. These results suggest that image analysis has the potential for being a useful tool in selecting areas for drilling and stimulating wells to enhance hydrocarbon production. Of particular interest are the extremely tight formations which contain large amounts of gas, such as the Devonian Shales. Migration of the gas within the shale matrix is primarily a diffusion process. Hence, to have a good reservoir requires the presence of a large natural fracture system and/or porous permeable sand stringers or beds within the shale formation. Therefore, it is important that a method for locating these productive areas be developed.

Current efforts are being directed toward surface joint studies, surface and subsurface geologic studies, airborne image analysis including high and low altitude aircraft and satellite images, and core fracture studies. Two areas, one in the vicinity of Cottageville, W. Va., and the other in the vicinity of Hazard, Ky., are being intensively studied. These areas were selected because they contain productive shale gas fields. Data collection for these areas is nearing completion and data correlation has been started. Results obtained to date suggest that a reasonable correlation

between surface joints, core fractures, core tensile strength and lineaments derived from airborne imagery may be expected. Much additional work will be required to identify the keys needed to locate fractured hydrocarbon reservoirs.

Log/Core Correlation Studies

Geophysical well log analysis and interpretation is now being refined to more accurately locate zones of greater fracturing, porosity, and gas content of the Devonian Shale. Some of the techniques are promising for better reservoir evaluation of the Devonian Shale.

Gas productivity in the Devonian Shale can usually be correlated with zones of higher organic content and more intensive fracturing as shown by core and log analysis. Normal fracturing or jointing in the shales is one vertical fracture usually oriented in a northeasterly direction. Where gas enters the borehole, usually two or more vertical fracture directions are evident, often at right angles to each other. These zones are most usually intervals of higher organic content. Core and log analysis show that the shale porosity is very low, ranging from less than 1 to over 5 per cent, averaging 2 to 4 per cent. Free fluid saturation is probably close to 100 per cent hydrocarbon as no connate water has been produced from Devonian Shale wells.

A total of six Devonian Shale wells have been cored and logged, one in Perry County, Ky., two in Jackson County, W. Va., and three in Lincoln County, W. Va. Natural gas production from the wells has ranged from zero to over one million scfd. The thickness of the Devonian Shale ranged from 400 feet thick in the Perry County, Ky. well to 1400 feet thick in the Lincoln County, W. Va. wells. Over 3,000 feet of oriented core has been recovered from 5 of the 6 shale wells, ranging from 1,345 feet in one Lincoln County well to 287 feet in one of the Jackson County wells.

Oriented Core Characterization Studies

Oriented core characterization is a major part of the in-house program in the assessment of and reservoir considered for stimulation to enhance the engineers' understanding of how production might be augmented.

The initial phase of obtaining and preparing the shale core for the laboratory begins at the well site. Here the shale is cored approximately 60 feet at a time. The core is carefully handled and reassembled in the field for the purpose of cleaning the core, marking the depth, wrapping the core and then boxing 3' core sections.

The initial work with the core at the Morgantown Energy Research Center begins with proper labeling of boxes for storage. Once this phase is completed, the first test is the relative hardness of the core. The relative hardness of the core is accomplished by the use of a scleroscope.

After this stage is completed, the complete reassembling of the core is required. This is to allow for the proper orientation of the core in the shale formation. The goniometer is the instrument which allows one to properly orient the core section with the four major compass points. The next phase is to record all fractures (their orientation, frequency, and length). A general macroscopic lithologic description is then recorded. Any descriptive or special characteristics of the core sections are also noted for the photographing sequence in the lab.

The selection of samples for additional testing may occur at this stage with samples for Fischer assay, modulus testing, permeability and porosity, x-ray, and any other necessary tests.

The ultrasonic velocity samples are also chosen at this time. These are 6-8 inch specimens. The selection of samples for 2-inch line load, directional tensile strength tests, and point load tests is next. The marking of microfractures is also recorded on all directional/point load samples.

The compilation of all initial data concerned with geology, geography, lithology, logging, and fractures are then incorporated into final reports. This represents initial background information for future analysis and testing.

The final handling of the core is to archive each cored well in the core storage building at MERC for future reference.

Foam/Gas Frac Evaluation Studies

Current marginal gas well stimulation research is directed toward establishing a data bank of well treatments that have been and will be tried in marginal production areas such as the Devonian Shales of the Appalachian Basin.

As a part of this research, several in-house tests of the nitrogen/water foam frac technique have been performed. This method, consisting of 20-25% water and 75-80% N_2, is designed to minimize water damage of the Shale and to improve well clean-up time after frac.

A fairly typical example of our in-house field research was performed in Jackson Co., W.Va. Here, a Devonian Shale well with 156,000 gal. of foam and 155,000 pounds of sand was treated. Post-frac tests showed an open flow potential of 173 mcfd and a created vertical frac height of about 160 feet. The well is expected to deliver about 160 mcfd into the pipeline.

Other tests of foam fracturing have been conducted in Kentucky and Ohio, and currently, 3 more in-house foam data points in Kentucky are planned.

An unsolicited proposal has also been received to drill, core, and frac 9 Devonian Shale wells in Lawrence and Scioto Counties, Ohio. The objective is to test and evaluate foam and cryogenic vapor fracturing performance.

The proposer plans to frac 3 wells each with dollar-equivalent amounts of foam and vapor (140,000 gal. foam/50,000 gal. vapor), and to thoroughly evaluate the relative merits. The remaining 3 well set is then to be fractured with a larger version of the optimum treatment.

Statistical Analysis of Production History

Based on an ever increasing need for effective stimulation of the Devonian Shale section in the Appalachian Basin, statistical analyses are in progress to assess how effective past hydraulic fracturing treatments have been in terms of deliverability and to use this input to suggest some change in treatment design in order to increase productivity in future wells.

Regression analysis in conjunction with plots of the data and correlation tests were the main statistical tools employed to investigate hydraulic fracturing treatments from 24 wells stimulated in the northeastern part of Kentucky. The objective was to develop mathematical models to represent open flow per foot of net sand as a function of the reservoir and fracture treatment variables. The resulting model indicated that an empirical relationship developed for fracture length was the most significant parameter to the model. This relationship indicated an increase in fracture length would result in an increase in open flow potential. A further investigation of the empirical relationship for frac length and open flow potential revealed that a possible optimum with respect to open flow might result in a difference between instantaneous shutin pressure and bottom hole treating pressure to be near 1219 psi and an associated frac height of 97 feet.

Because of a need for increased deliverability of natural gas in the Clinton sandstone located in northeastern Ohio, an in-depth study of production history, well logs, and stimulation treatments from 328 wells located in this area is now underway. The objective of this study is to adjust controllable parameters in the fracturing operation to near optimum conditions in the presence of non-controllable reservoir parameters (porosity, net sand, gross sand, and in situ stress). Initial steps were proposed to look at contour plots of non-controllable reservoirs to see if they could suggest a method of approach from a regional standpoint. Also included in our study is to perform a discriminant-analysis-type procedure to develop a function that can be used to rank wells as to whether they could be classified low, medium, or high producers using both controllable and non-controllable parameters. If a reliable discriminant function can be developed, future controllable parameters could be adjusted to make the stimulation efforts more successful.

Much is to be learned about how past production history, well logs, and stimulation treatments can be utilized to help design future stimulation treatments for maximum productivity. All of our efforts in statistical analysis is directed toward helping us understand what parameters are controlling our wells' response to stimulation efforts.

Cost-Effective Analysis of Stimulation Techniques

A program will be initiated to determine and analyze the cost-effectiveness of the various technqiues that are being developed for stimulation of natural gas wells.

The need for this program arises from the fact that the number of alternatives for stimulation R&D has been increasing and will continue to increase at a high rate. Due to the technical competence of the innovation of many of these alternatives, some criterion other than technique is needed to evaluate the utility of these alternatives.

Once a comprehensive model is constructed, it is envisioned that the cost-effectiveness of a viable technique can be optimized via parametric-sensitivity analysis. Furthermore, the model will be used to generate extensive cost data that will serve as a decision making tool.

Data for the study will be acquired from cooperating companies holding ERDA contracts and is expected to be complemented with analyses from the Lawrence Livermore Lab.

Fracture Mechanics Studies

Hydraulic fracture research, and in particular, the fracture mapping research, was initiated to delineate some of the critical issues associated with the hydraulic fracturing process.

The initial objectives were to determine the direction and lengths of hydraulically induced fractures. Subsequent investigation showed that the problems and questions to be addressed were of a more fundamental nature. Concepts, among the industry leaders, of the entire process from the wellbore pressurization stage have been found to widely vary, be contradictory, and some proven erroneous. Therefore, a program was developed to obtain answers to the fundamental nature and controlling mechanisms of the process.

The program encompasses reservoir pressure testing, acoustic mapping of fractures, potential resistivity mapping of fractures, fracture stress distribution, fracture directional control, fracture propagations characteristics, fracture modeling, design and correlation, frac well bottom hole pressure monitoring, and laboratory property evaluations and process simulations.

TABLE 1. - ESTIMATED GAS RESOURCES AND FORMATION CHARACTERISTICS OF THE MAJOR BASINS [1]

Location (essentially proved area)	Formation	Depth, feet	Gross interval, feet	Net pay, feet	Porosity, percent	Water saturation, percent	Effective permeability, md	BHP*	BHT**	Area square miles	Gas-in-place total trillion cubic feet
Piceance Basin Colorado											
Northern half	Fort Union and Mesaverde	5,600-9,700	4,100	965	9-10	50	0.007-.025	2,360-3,640	170-230	300	67.1
Southern half	Mesaverde	6,250-8,750	2,500	625	9	45	.020	2,750	204	250	36.1
Green River Basin Wyoming	Fort Union	8,000-12,000	4,000	700	9.2	54	.0034	6,820	203	140	37.1
Uinta Basin Utah	Mesaverde	8,000-11,000	3,000	1,000	10	50	.007-.015	4,300	200	300	101.6
San Juan Basin	Mesaverde	5,500 6,500	500	180	11	59	.14	-	-	2,000	32.0
	Pictured Cliffs	3,500 4,500	300	190	11	59	.14	-	-	1,500	31.0
Appalachian Basin	Devonian Brown Shale	3,000 6,000	600-3,000	200-400	2	10	.01	400			285.

* Bottom-hole pressure, psi.
**Bottom-hole temperature, °F.

TABLE 2. - STIMULATION TECHNOLOGY PROGRAM ACTIVITIES

* * * * * * * STIMULATION TECHNOLOGY * * * * * * * *

SUPPORT RESEARCH	ACTIVITY
PROJECT 1 -- EARTH FRACTURE SYSTEMS FOR ENERGY RESOURCE EXPLOITATION	1. Natural Fracture Delineation by Remote Sensing 2. Oriented Core Characterization 3. Log/Core Correlation of Productive Intervals
PROJECT 2 -- DEVELOPMENT OF MARGINAL GAS RESOURCES BY FRACTURING	1. Statistical Analysis of Production History 2. Foam or Gas Frac Design Technology 3. Evaluation of Induced Fracture Geometry 4. Cost/Effectiveness Studies of Stimulation Processes

CONTRACT RESEARCH	ACTIVITY
PROJECT 3 -- DEMONSTRATION PROJECTS	1. Explosive Fracturing Technology 2. Foam/Gas Frac Technology 3. MHF Technology 4. Dual Completion Technology 5. Deviated Well Technology 6. Fracture Mechanics TEchnology 7. Remote Sensing Technology

TABLE 3. -- CONTRACTOR, SCOPE OF WORK, AND TARGET OF DEMONSTRATION PROJECTS

CONTRACTOR	SCOPE OF WORK	TARGET OF DEMONSTRATION PROJECTS
El Paso Natural Gas	Massive Hydraulic Fracturing	Green River Basin
CER Geonuclear	Massive Hydraulic Fracturing	Piceance Basin
Austral Oil	Massive Hydraulic Fracturing	Piceance Basin
Mobil Oil	Massive Hydraulic Fracturing	Piceance Basin
Rio Blanco	Massive Hydraulic Fracturing	Piceance Basin
Coastal States	Massive Hydraulic Fracturing	Uinta Basin
Pacific Transmission Supply	Massive Hydraulic Fracturing	Uinta Basin
TAO-Westco	Massive Hydraulic Fracturing	Uinta Basin
Columbia Gas	Massive Hydraulic Fracturing	Appalachian Basin (Shale)
Petroleum Technology Corp. (2)	Explosive Fracturing	Appalachian Basin (Shale)
Proposed Project	Massive Hydraulic Fracturing	Appalachian Basin (Shale)
Proposed Project	Deviated Wells	Appalachian Basin (Shale)
Proposed Project	Deviated Wells	Appalachian Basin (Shale)
Columbia Gas	Massive Hydraulic Fracturing	Appalachian Basin (Sand)
Proposed Project	Recompletion	Appalachian Basin (Sand)
Physics International	Explosive Fracturing	Appalachian Basin (Sand)
Petroleum Technology	Explosive Fracturing	Canyon Sand
Dallas Production	Massive Hydraulic Fracturing	Bend Conglomerate

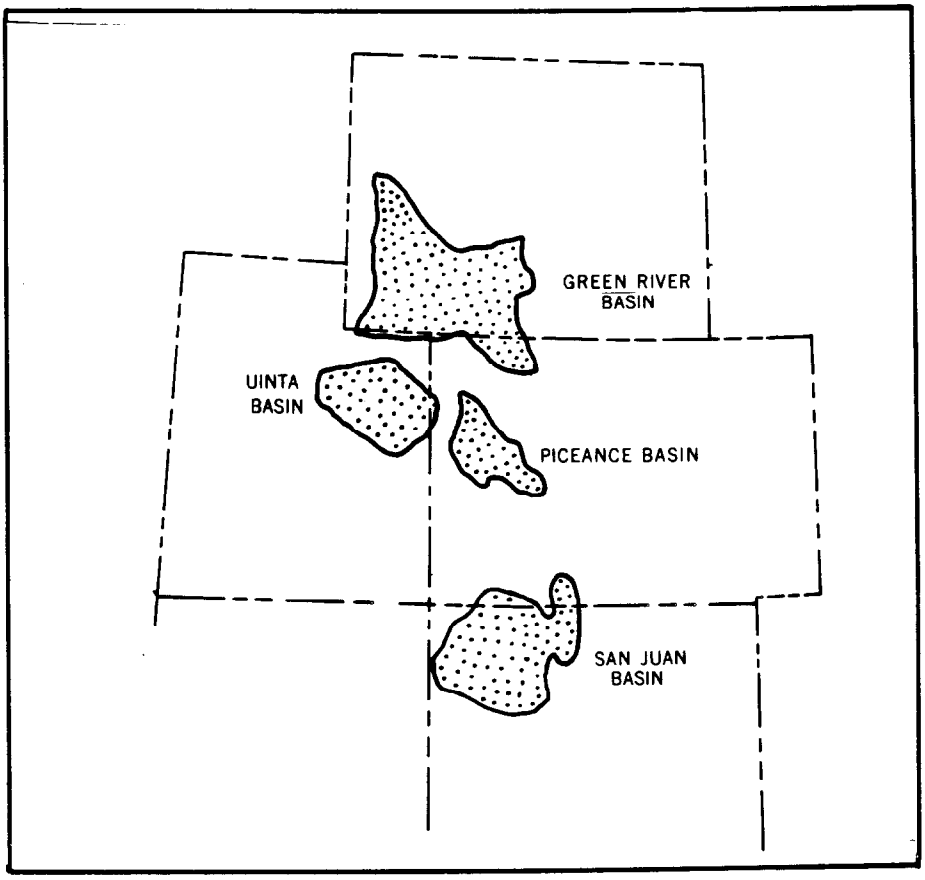

Fig. 1 - Location of major gas deposits which merit consideration for stimulation in the Rocky Mountain Basins.

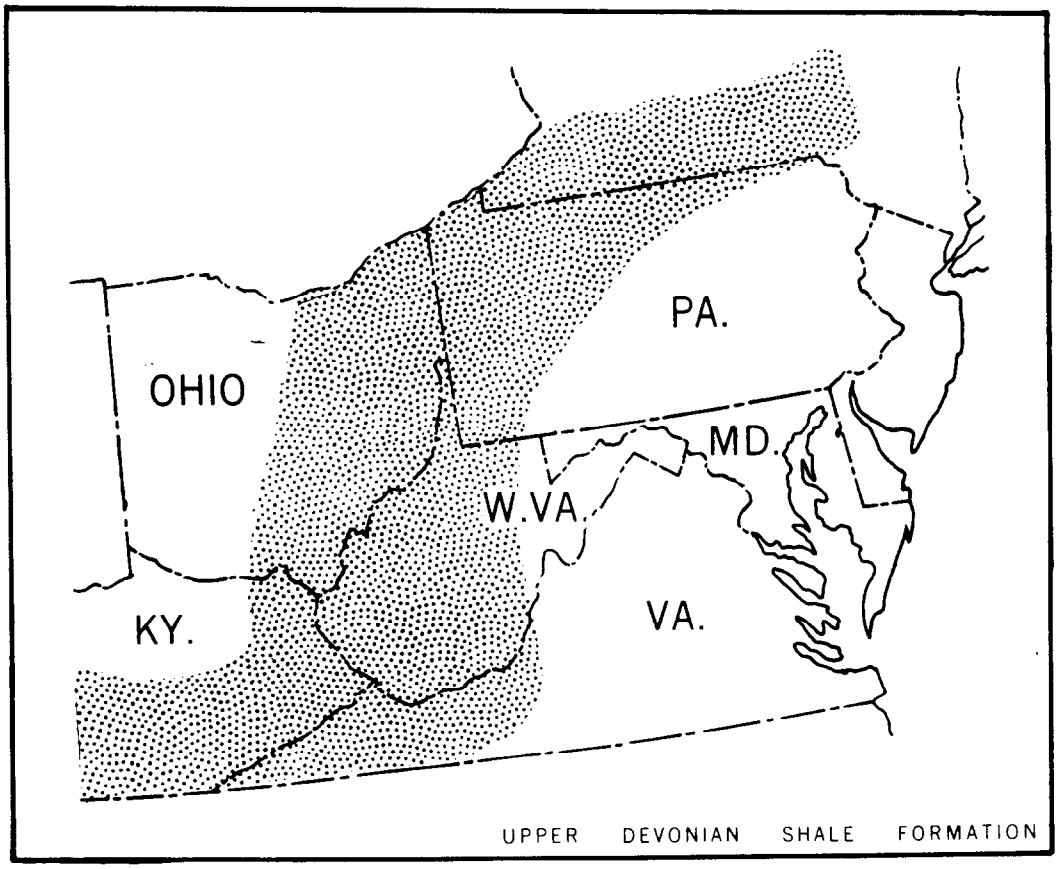

Fig. 2 - Location of major gas producing regions which merit consideration for stimulation in the Devonian Shale.

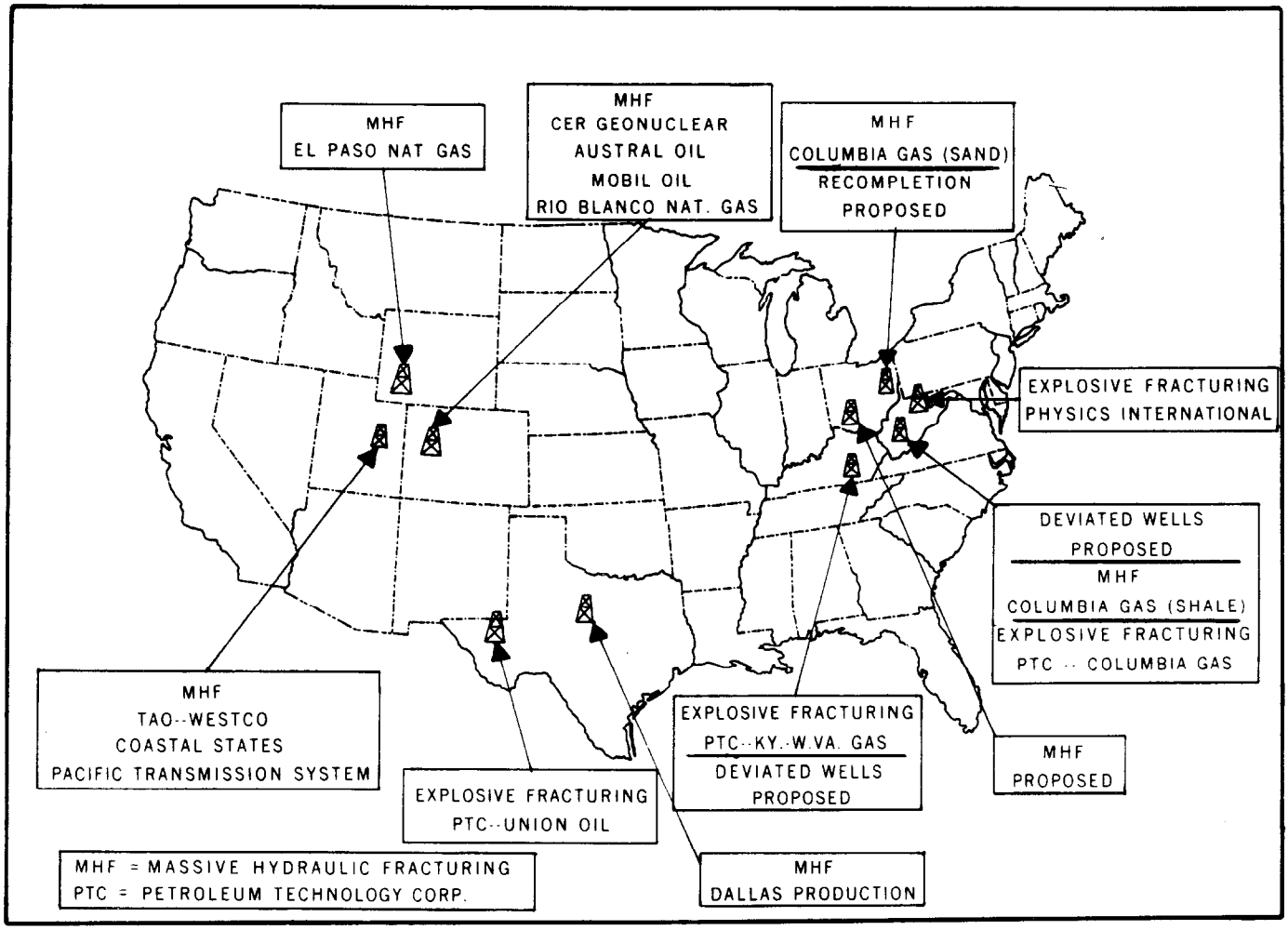

Fig. 3 - Test sites of ERDA sponsored research projects.